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WHAT THE STATION HAS DONE IN 1936-37

Annual Investigative Report
Lake States Forest Experiment Station*
Forest Service, United States Department of Agriculture

*Maintained in cooperation with the University of Minnesota at University Farm, St. Paul, Minnesota.

ANNUAL INVESTIGATIVE REPORT

Table of Contents

	Page
Progress in tree planting	
Summary of findings	1
Planting the major activity in the Region	2
The problems and research applicable to them	3
Drought--the teacher	4
Bigger stock--better survival	5
Heat, drought, or both?	7
Older plantations survive well	7
Tests of drought resistance	8
New device measures use of water by trees	9
Advantages of planting aspen and brush lands in drought years	10
The drier the site, the better should be preparation of ground	10
Seed studies	10
Forest fire research	11
Findings of shelterbelt-influences study	12
Water circulation studies	13
Timber cutting studies	
Summary of findings	14
Managing jack pine for pulpwood	15
Soil treatment stimulates jack pine reproduction	17
Sustained yield in northern hardwoods	17
Statistical analysis of forest measurements	18
Forest economics	
Summary of findings	19
Forest labor and employment studies needed	21
Woodland study proposed	21
Cost and price studies	21
Recreation	22
Extension of survey	22
Publications	23

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WHAT THE STATION HAS DONE IN 1936-37

PROGRESS IN TREE PLANTING

Summary of Findings

1. The Regional plan calls for annual planting of some 125,000 acres and expenditure of approximately a million dollars.

2. The demand for prairie and plains planting is constantly growing.

3. The Experiment Station must meet the demand by increasing its planting research and reorienting it to meet the immediate practical needs of the Region.

4. Although the Station has established over 1,100 acres of experimental planting plots, past efforts have been confined to a few localities in the Region and often with too much emphasis on the physiological phases. The future plans, in addition to continuance of the long-time studies, include large-scale experimentation of a more practical nature over a wider territory and of a character immediately applicable to field conditions.

5. The drought of the last few years emphasized the weak spots in our planting technique.

6. The drought has conclusively proved that the bigger the planting stock the better the chances of withstanding unfavorable climatic conditions.

7. Surface heat, which at times reached 175° F., often causes greater loss than lack of moisture.

8. Laboratory experiments corroborated by field experiments show that temperatures of 130° F. are fatal to small planted trees.

9. Plantations 15 years and older are fairly safe from drought; those 10-15 years old may suffer considerable but not serious loss; plantations 5-10 years are subject to serious losses; and those younger than 5 years may be completely ruined during a very severe drought.

10. Shading of plantations by adjoining living trees, dead brush, or other artificial means increases survival during drought years.

11. Seedlings subject to periodic dryness in the nursery are more drought-resistant than those which are watered copiously and continuously.

12. Drought resistance of green ash is in direct ratio to the dryness of the climate of its origin. Green ash from western North Dakota is the most drought-resistant; from South Dakota it is moderately drought-resistant; and from Kansas, Iowa, and western Minnesota, least drought-resistant.

13. A device was perfected to study the comparative loss of water by different species as a basis of their adaptability to prairie and plains planting.

14. Planting under aspen or in brush, providing competition has been removed, has better prospects of survival during drought years than in the open.

15. The drier the site the more thorough must be the preparation of the ground. Subsoiling increased survival by 30 percent.

16. All planting experiments whether in the nursery, transplant bed, or in connection with preparation of the ground must be coordinated and tested by one standard, viz., survival in the field.

17. Seed studies resulted in improved technique for hastening germination by means of pretreatment; a very efficient seed scarifier was designed; and about 1,000 articles were abstracted for the "Manual of Tree Seeds of North America."

Planting the Major Activity in the Region

The Lake States has undoubtedly the largest acreage in need of forest planting. The annual planting program of the Region calls for reforestation of an area of 110,000 to 125,000 acres. This will require in excess of 100 million plants a year. The Region is not satisfied with the success so far attained in past planting. In 1935 some 105,000 acres were planted by the national forests in the Lake States. At average cost of say $10 an acre, this represents an annual expenditure of more than a million dollars a year. These facts clearly show that planting is one of the most important activities of the Region and will remain so for many years to come.

Some of the failures of past planting were undoubtedly due to the newness of the job, lack of trained personnel, and an organization based on temporary emergency workers. As the work progresses, many of these organizational drawbacks will gradually disappear. There are, however, many technical problems which can be solved only through careful observations, scientific experimentation, and better understanding of all physical and biological factors that enter into a successful planting program.

In the past the Experiment Station, partly due to limited funds and a different orientation of its work because of the absence of large-scale planting operations in the Region, confined its efforts to a few

fundamental problems, either of a laboratory character or intensive studies on a small scale. With a large-scale planting program now actively under way the Region is in need of information of immediate practical application, which in turn demands a new orientation of our planting studies and experiments.

As a result of these changed conditions this Station from now on, in close cooperation with the Region and with financial help from the Region, is going to undertake studies of more immediate practical character that can give an answer at a comparatively early date to the more pressing planting problems. This does not mean abandoning altogether the long-time studies. On the contrary, it even involves an expansion of certain present studies; this, however, with an adjustment to the immediate planting needs.

The major planting problems of the Region and the extent to which research has attempted or not attempted to solve them are given below:

The Problems	Research Applicable to These Problems
1. Planting in the sand plains	Series of planting experiments on Huron National Forest, Michigan. Jack pine best species; large, well-developed stock gives greatest success. Work on Huron needs to be supplemented on Manistee and other national forests in Michigan.
2. Planting under aspen and brush	Studied intensively on Chippewa National Forest, Minnesota. Results fairly conclusive. Need to apply to large-scale operations in Minnesota in a practical and relatively inexpensive way. Similar application needed on Wisconsin national forests.
3. Planting of spruce	Very little done. Need for introducing spruce in hardwood soil and land originally occupied by spruce and white pine in Wisconsin forests and Superior National Forest, Minnesota.
4. Fundamental studies:	
Source of seed	Some 154 sources of Norway pine and 30 of Scotch pine tested. Work should be extended to spruce.
Effect of shade	Intensive "laboratory" experiments on effect of light carried on in Chippewa National Forest and extensive field observations in Michigan. Should be applied on a large scale and in a practical way.

Effect of cultivation	Tried out machine cultivation very effectively in sand hills of North Dakota both with hardwoods and conifers. Perhaps has also a place in Lake States planting. Hand cultivation is now being tried in Michigan.
Resistance to high and low temperatures and drought	A number of intensive laboratory experiments, not entirely conclusive. Has application to hardening off of nursery stock in fall. Much more needs to be done.
5. Nursery investigations	Need practical studies of fertilization, density of sowing, nursery-wide grading, etc. Nothing done with conifers.
6. Close coordination between nursery practice and field planting	In the past these activities were largely independent and not correlated. Experiments needed to make field survival tests of stock grown in the nursery under different conditions, density, fertilization, etc. This is important and thus far only indications exist here and there.

The development of nursery stock and of planting technique that will secure a high survival in the field is the principal objective and the real test of the success of forest planting. It should go through as the red thread throughout all nursery and field planting experiments. A more detailed discussion of the results obtained in our planting experiments follows.

Drought--the Teacher

The great drought of 1936, with its blistering heat and desiccating, searing winds, left its mark of destruction not only on the farms of the Lake States and prairie regions but on the forests as well. Despite the havoc it wrought, it served to point out sharply the weaknesses in our planting practices, weaknesses which under normal conditions we would not have learned in many years. It is for this reason that the effects of drought and the lessons it taught us are discussed in considerable detail.

Comprehension of the drought's severity may be gained from the general summary reports included in the Monthly Climatological Bulletins issued by the U. S. Weather Bureau. We learn that for the State of Wisconsin the month of June was the driest on record since 1912, that July was the driest on record since 1894. In Minnesota only three Junes in the past 46 years were drier than 1936: July was the driest at Minneapolis since the beginning of weather observations at Fort Snelling

in 1837. Turning to Michigan we find that drought conditions were already becoming severe in late May in Lower Michigan, and that there was only one drier May on record for the state. June was the fourth consecutive month with subnormal precipitation.

A perusal of weather records for the year 1936, however, fails to indicate the severity of the drought, if annual averages alone are considered. Although the record at Bemidji, Minnesota, showed a deficiency of 8.33 inches (about 2/3 of normal), that at East Tawas, Michigan, showed a deficiency of only 0.61 inches. The real damage of the drought, which on the average, lasted approximately from June 20 to August 15 in the three states, was done in July when abnormally high temperatures were recorded throughout the whole Region. The average monthly temperature for July was 6° above normal at Rhinelander, Wisconsin, 7° above normal at Bemidji, Minnesota, and approximately 2° above normal at East Tawas, Michigan.

Throughout the three states the period lasting approximately from July 7 to 14 showed maximum daily temperatures of 100° or more for 5 to 7 days of this period.

Such extremes of drought and heat left their toll on the forest. This loss was greatest in the most recent forest and shelterbelt plantings. In some locations whole plantations were entirely wiped out. Even among plantations and natural reproduction as old as 10 years the injury was severe.

A specific study was made of an area of 9-year-old natural reproduction of jack pine on the Huron National Forest, Lower Peninsula of Michigan. In this stand, which averaged 1,880 trees per acre, only 52 percent of the trees emerged without evidence of damage; 30 percent were killed outright; and the remaining 18 percent, although still alive, were injured by drought and heat.

Bigger Stock--Better Survival

Lake States Region. Results of the comprehensive planting experiment conducted by the Station on the Huron National Forest, Michigan, again hammer away at the same point, which has shown up in each year of the experiment's existence. Based on the analysis of some 6,500 trees, Norway pine planted in the fall of 1935, for example, showed the following survival percentages at the end of 1936, the worst drought year on record in that locality: 1-0 stock, 5; 2-0 stock, 14; 1-1 stock, 18; 2-1 stock, 38; and 2-2 stock, 59.

The same point is brought out from a different angle by a special mortality study made in the fall of 1936 which involved the examination and excavation of 5,200 trees on 26 plantations on the Huron National Forest. This study showed that, on the average, the trees which died in 1936 were smaller and had less vigorous root development than those which lived. Both studies point to the use of larger, better-developed planting stock to improve survival.

On the Plains. Further corroboration that larger stock is capable of withstanding both heat and drought is furnished by experiments conducted at Mangum, Oklahoma. In 1935 and 1936 the Lake States Forest Experiment Station made a test using over 20,000 seedlings of 14 different species of hardwoods graded into various size classes, using caliper (diameter of the stem) at a point 2 inches above the ground line and height of top as a basis of measurement.

The year 1936 provided a severe test of the stock, since rainfall for the first 8 months of the year was only 26 percent of normal and on November 1, at which time survival counts were made, was still only 55 percent of normal. The results of the plantings made between December 1935 and February 1936 brought out the following points:

1. Survival varied directly in proportion to caliper of the stock. Fairly large stock of about 1/4-inch caliper gave best survival; small stock gave poor survival.

2. The seedlings on the basis of survival were grouped into three classes and generally showed survivals as follows: Premium grades, 75 to 99 percent; marginal grades, 40 to 75 percent; culls, 5 to 40 percent.

3. For most species trees under 4/32-inch caliper are culls: those of 5/32-inch and 6/32-inch caliper are marginal; trees above 6/32-inch caliper and up to 16/32-inch caliper are premium grade. The use of larger than 16/32-inch gave good survival but materially increased planting cost.

4. Expressed on a basis of total green weight in ounces per seedling, culls are trees weighing under 0.2 ounce; marginal grades weigh between 0.2 and 0.5 ounce; premium grades weigh 0.5 ounce or over.

5. Small trees of species that grow slowly in the nursery gave better survival than small trees of fast-growing, succulent species.

6. Good-sized stock was less subject to blowing out and drought loss on sandy knolls.

7. The premium grades showed almost twice as much height at the end of the first field growing season. For instance, the large grades of black locust averaged 50 inches while the small grades averaged 29 inches.

8. The larger reserve of stored food in the premium grades aids in rapid establishment of their root systems, thus making them less subject to midsummer drought than small seedlings. Examinations of root systems of the trees at the end of the first growing season showed that the larger planting stock had a wider and often deeper root system.

9. Top-root ratio on a green-weight basis has little, if any, relation to field survival of deciduous stock planted in the Great Plains. In fact, the larger grades, which gave the best survival, had the poorest top-root ratio, while the smaller grades, which survived poorly, had the best top-root ratio.

10. The survival data, when interpreted in terms of nursery production, indicated that densities of 4 to 12 seedlings per lineal foot of row, with an inter-row space of 18 to 24 inches, gave the maximum number of premium-grade seedlings.

Heat, Drought, or Both?

So-called droughts, as a rule, are characterized not only by moisture deficiency but also by abnormally high temperatures. As a consequence, plantation mortality during such years is usually affected by both factors. Commonly no differentiation is made between drought and heat damage in the field; but inasmuch as the proper solution of the planting problem is somewhat dependent on such differentiation, an attempt at accurate diagnosis of drought and heat damage was made in the special mortality study already alluded to.

Heat injury was evident in the field by the discolored ring of "cooked" cambium found on the smaller trees, usually within 1 inch of the soil surface. In a few cases such "dead" trees were found which still had live roots, indicating definitely that drought did not cause death. The heat was not intense enough to girdle larger trees (over 1/2 inch in diameter at the root collar), but did cause lesions on the southwesterly sides of many such trees which are still living, as well as those which finally succumbed to drought. Previous laboratory tests have shown that 2-hour exposures to temperatures of 135° F. are lethal for 2-2 Norway and white pine stock. Thermograph records taken on the Huron National Forest experimental plots during 1936 showed a new maximum temperature of 175° F. at the soil surface in the open and one record of $8\frac{1}{2}$ consecutive hours with temperatures above 130° F. This definitely shows that the possibilities of tremendous heat damage were present. Soil-moisture samples taken throughout the year also showed that there was sufficient moisture deficiency to bring about death in several localities.

As a result of this diagnosis, heat was found to be the major mortality factor in 1936, with drought second and other causes of little importance. In 10 jack-pine plantations, averaging only $2\frac{1}{2}$ years in age from seed, heat caused nearly 74 percent of the mortality, drought 26 percent, and other factors a negligible amount. For 16 Norway-pine plantations which averaged nearly 7 years in age from seed, heat caused nearly 58 percent of the loss, drought 41 percent, and other factors 1 percent. The lower heat loss for Norway pine was apparently due to the greater average age of the trees and the slightly more abundant cover protecting them.

Older Plantations Survive Well

A study of older plantations throughout northern Minnesota, Wisconsin, and Michigan indicated that plantations which have reached 10 years in age show comparatively little loss in the ensuing 10 years. Three hundred and eighty plantations averaging 23 years in age showed a mean loss of 16 percent in survival over the 12-year period from 1924-1936.

Studies and observations made during the past 4 years on the Huron National Forest indicate that under the relatively difficult conditions there the Norway-pine plantations which have reached 15 years in age are relatively safe, those 10 years old may be subject to noticeable loss, those between 5 and 10 years may suffer heavy loss, and anything younger than 5 years may be severely hit in such years as 1933 and 1936.

A detailed examination of a 15-year-old Norway-pine plantation made on the Huron National Forest in 1933 after the severe drought of that year (which locally was as severe as that of 1936) showed that trees without benefit of shade had a survival of 29 percent while those shaded had a survival percentage of 62 percent. The data further showed the benefit of oak, under which 70 percent of the Norway pine survived, as compared with jack pine, under which only 44 percent of the planted trees survived. Furthermore, a survey of twenty 1-year-old national forest plantations made in 1934 consistently showed that trees planted under shade had from 30 to 40 percent better survival than those grown in the open.

The inference is that, in order to guard against the loss caused by such excessive heat, the first step is the use of larger stock, and the second, taking advantage of natural shading or possibly resorting to artificial shading either by the use of dead brush or some other means.

Tests of Drought Resistance

The apparatus for testing drought resistance of plants installed first in 1932 has been further perfected. The new machine holds 200 plants and has very accurate temperature and humidity controls.

Five species were tested, viz., green ash, white pine, Norway pine, jack pine and Norway spruce. The tests were aimed first to determine whether the degree and method of watering had any effect on drought resistance; second, to find out whether the source of seed of green ash had any effect on drought resistance of the seedlings; and third, to determine to what extent the findings in the laboratory checked with survival in the field.

The conclusive evidence is that conifer seedlings subjected to periodic soil dryness are more drought-resistant than seedlings grown with an abundant continuous supply of moisture.

In the case of green ash it has been shown that the seedlings grown from seed collected in northwestern North Dakota are most resistant to drought, those from eastern North Dakota and most of South Dakota are fairly resistant, while those from western Minnesota, Iowa, and Kansas are least resistant. This agrees with the amount of precipitation in those three regions, drought resistance being in inverse ratio to precipitation. This, however, is only one factor to be considered when planting trees or tree seeds, which have come from a region of less abundant precipitation, in one of greater precipitation.

Both nursery-grown stock and plants grown in the greenhouse have been subjected to the laboratory tests. The effectiveness of the laboratory method has been checked against tests in the field and the two prove to be in very close agreement.

New Device Measures Use of Water by Trees

The success of forest planting in the prairie-plains region depends in a large measure on the use of trees and shrubs which can withstand severe drought conditions. The ideal species for this purpose would be those economical in their use of water, those which could produce large amounts of foliage (thus having a high windbreak value) with a minimum amount of water.

In order to determine how the various trees and shrubs now being used for plains planting meet these requirements, an apparatus has recently been built by Messrs. Minckler and Bates of the Station staff, which actually measures the amount of water used by small trees under field conditions. This consists of a chamber 4 feet high and 2 feet in diameter, resembling a bird cage covered with cellophane. After covering the ground under the tree with canvas to prevent evaporation from the soil, the chamber is placed over the tree to be measured. An exhaust pump maintains a continuous flow of air through the chamber. A sample of this air is drawn through a series of six drying tubes which are weighed at intervals to see how much moisture is absorbed.

To determine how much of this moisture consists of that lost by the tree through its leaves, a comparison must be made immediately with air not affected by any particular vegetation. For this test the apparatus is set up at a nearby point and the air moisture measured in the same way. The difference between the two readings represents the amount of water lost by the trees through its leaves.

Field trials made with the apparatus during the past summer show interesting features concerning the water use of various species. Since Chinese elm roots widely and vigorously, has leaves which persist throughout a long growing season, and makes rapid woody growth, it might naturally be expected to cause a heavy drain on soil moisture. This is well borne out by tests made with the apparatus in Oklahoma. During hot, dry weather, a Chinese elm 3.3 feet in height lost water at the rate of 2 pounds per hour (1.4 liters or about 3 pounds per hour per square meter of foliage) in the morning, but less than a fifth as much in the later afternoon.

None of the other species tested under similar conditions approached such a high rate as Chinese elm. Yet this species, in the juvenile stages, outclasses practically all other trees in withstanding drought, as shown by actual field survival tests. The question is whether, in the long run, Chinese elm is likely to prove one of the most desirable species because of the extent to which it exhausts soil moisture.

It is believed that the apparatus will be of considerable help in obtaining a new "slant" on the performance of the various species, and probable performance when drought becomes a critical factor.

Advantages of Planting Aspen and Brush Lands in Drought Years

Planting aspen and brush land, providing the root competition and shade are properly controlled, particularly during drought years, results in better survival than planting on open sandy soils, both because of the better soil and because of partial shade.

The possibility of converting aspen and brush lands to conifers has been fully demonstrated on the Chippewa National Forest. The problem reduces itself to control of overhead shade and elimination of shade and root competition of the understory plants. It now remains to be demonstrated that it can be accomplished on a large scale in a practical way and at a reasonable cost.

The Drier the Site, the Better Should Be Preparation of Ground

Experience gained in prairie-plains planting clearly brings out the need of careful preparation of the ground, summer fallowing on difficult sites, and subsequent cultivation if the trees are to survive. Special soil preparation, such as "subsoiling" on the heavier soils, increased survival 30 percent in the tests made. The use of a subsoiling plow so loosened the soil that much better planting resulted. Without such treatment it was more difficult to plant trees properly without distorting the roots.

Although such extreme practices as subsoiling are probably not justified in the Lake States, indications are that thorough ground preparation in order drastically to reduce plant competition for several years is necessary. In certain areas, especially of light sands, however, where plantings established under standard practice have repeatedly failed, it is quite possible that cultivation may prove to have some application.

Seed Studies

1. Seven hundred and seventy-three germination tests covering 96 species were made. Of these, 407 were experimental samples and the remainder routine tests for Federal nurserymen.

2. The technique of seed testing and the behavior of seed of different species were studied. This information is being incorporated into a "Manual of Tree Seeds of North America," which also brings together all available information on seed. Nearly 700 species are involved. Over 1,000 different articles are summarized. Other experiment stations are cooperating in the preparation of this manual.

3. Studies of the effect of different methods of storing white-pine and Norway-pine seed begun in 1930 have yielded the first definite results. The advantages of storage at low temperatures and in sealed containers are clearly indicated. Under such methods seed of white pine may be stored for 5 years with no loss in viability, a feature of considerable economic importance, especially with species bearing seed only at long intervals.

4. Studies of pretreating seed to hasten germination were extended to seed of 40 species. Both mechanical and chemical methods were used. Experiments have shown in the case of such species as red cedar that pretreatment may shorten the period required for germination from a year to only 30 days.

5. A seed scarifier was perfected, of particular use with black locust or other species having a thick seed coat. This machine does in 15 minutes what required 3 days with the old type of equipment.

FOREST FIRE RESEARCH

1. The Lake States have made undisputed progress in fire protection, in spite of an exceptionally dry year in 1936 when conditions were just right for big conflagrations. Although the threat of large conflagrations was ever present and numerous small fires were burning, the organization of the fire-protective force prevented a serious disaster. The area actually burned over amounted to 88,000 acres, or not more than 0.84 percent of the total land area. Considering the extreme weather conditions, this compares very favorably with the 5-year average of 0.74 percent.

2. The attack on the fire problem by the Experiment Station has been reoriented. In the past, Region 9 being in process of growth and development with new areas of national forests added almost every month, the fire organization and fire problems of the Region had not had time to crystallize. For this reason, fire protection except on a few older units has been in a nebulous state. Today the Region has become more settled and the fire problems are more specific, all of which makes the goal much more concrete and definite.

3. During 1936 effort in forest-fire research was devoted to Service projects such as aiding in the inspection and establishment of fire danger stations on the national forests, analyzing local fire and weather data, preparing instructions, and otherwise cooperating with the Regional Office and national forest officers.

4. Results of the rainfall-probability study were issued for field use in the form of an atlas of 22 charts, showing for each 10 days, from April 1 to October 31, the probability of 0.50 inches or more of rain throughout the northern Lake States region. These data were later summarized for the Region as a whole, by states and by major state subdivisions, in the July-August issue of the "Research Digest." These charts show where and when a deficiency of precipitation is most likely to occur, and are intended primarily for the use of forest

in protection planning. They have, however, been of considerable interest to agriculturists, and the Horticultural Department of the University of Minnesota is considering the extension of them to cover the balance of Minnesota.

5. A "Fire Hazard Index" was prepared, for the use of State and Federal forest officers in determining the degree of fire danger prevailing currently. It was used during the past fire season by some 31 forest officers and proved to be of considerable value. It has since been revised and extended on the basis of more complete data now available to cover a wider range of conditions, and will be reissued in the form of a fire-danger meter for use during the coming fire season.

6. No new fire studies were started in 1936 and none are contemplated for 1937, since cooperation with the Regional Office and national forests will take all the time and funds not needed to complete and carry on projects already under way.

7. To make possible closer coordination of fire research with the national forest problems, some one national forest should be selected as an experimental fire forest on which the application of fire-research methods should be consolidated. This would make possible a better mutual understanding of the problems presented and better cooperation in the application of research results.

FINDINGS OF SHELTERBELT-INFLUENCES STUDY

1. The studies of the effect of windbreaks were conducted at Towner, North Dakota; Huron, South Dakota; Holdrege, Nebraska; Dodge City, Kansas; and Childress, Texas (to July 1, 1936).

2. The intensive experiments of 1936 firmly established that shelterbelts of trees are principally valuable and necessary for protecting highly erodible and sandy soils in the plains.

3. The windbreaks need not be broad or dense, as was thought at the beginning of the experiments. They should be in the nature of light "screens" obtained by the use of a few rows of tall trees. These windbreaks, however, should be placed rather close together on all sides of the fields. The "screens" of trees should be reinforced by shrubs, particularly as the trees become older and tend to lose their lower limbs.

4. A detached windbreak on one side of the field, or even if the field is surrounded completely by windbreaks but with no windbreaks around the adjoining fields, cannot be very effective. A fundamental requirement of effective wind protection is cooperation between neighboring farmers in such a manner that the plantings made by each become interacting and of common benefit to the whole community. If one neighbor does not take any interest in the matter, the farmer who has erected his barrier may actually find both his trees and his crops buried by soil from adjacent land.

5. Frequent light wind barriers, both north and south and east and west, are most beneficial on sandy soils and are fairly easily established on such soils. Trampling by stock, which would ordinarily occur in fields other than regular pastures, is not likely to be very damaging on these light soils. These narrow belts of trees on light soils, therefore, need not be fenced off from the fields, which was a large item of expense in the original calculations of the cost of shelterbelt planting.

6. Planting of shelterbelts, particularly around fields on the hard upland soils, especially in the drier western portion of the plains, is difficult and hardly justifiable by the results obtained. Such planting, however, may be justified for aesthetic purposes and for providing protection for livestock, homes, etc.

7. Experiments at Holdrege, Nebraska, show that, with small test houses of good construction about equal to the average farmhouse of the plains in tightness and insulation, windbreaks may effect fuel savings of 30 to 50 percent, especially when many conifers are used in them.

8. The velocity of direct cross winds is reduced by good windbreaks by as much as 10 percent on the leeward side for a distance of about 25 times the height of the trees.

9. With the possible exception of North Dakota which is subject a great deal to west winds, the year-round observations show that windbreaks in an east-west direction in the aggregate obstruct more wind than those which are north-south. This is in spite of the fact that in all latitudes from North Dakota to Texas there are occasional violent storm winds for short periods from the west. Moreover, the south winds are warmer and drier than north winds. Any conservation of moisture, therefore, is likely to occur on the north side of shelterbelts.

10. The value of tree windbreaks to conserve the moisture of fields is less clear than their ability directly to reduce wind movement near the ground, to prevent soil blowing, and blowing-down of crops, and to control snow drifting in the north.

WATER CIRCULATION STUDIES

1. Ten large water-tight tanks, 10x20 feet in size, filled with soil to a depth of 4 feet, constructed at LaCrosse, Wisconsin, have now been under observation for a full year. These tanks, known as lysimeters, are for the purpose of measuring accurately runoff and the amount of water percolating through the upper 4 feet of the soil, and for determining the water loss through transpiration under several types of vegetative cover, or no cover at all.

2. The surfaces of some of these tanks were planted to Scotch pine and native hardwoods (oaks and black walnut), and in addition were mulched to a depth of about $2\frac{1}{2}$ inches. The surface of one tank was covered with gravel to a depth of about 2 to $2\frac{1}{2}$ inches and had no vegetative cover whatever. The trees are seedlings about 3 years old and, of course, cannot be considered in the nature of an ultimate forest cover, yet the first-year results were very enlightening.

3. The tanks which contained a layer of mulch and a stand of small trees had, before the vegetation was fully developed, a runoff of 4 to 5½ percent of the precipitation for the period. Percolation in these tanks varied from 1½ to about 6 percent.

4. The tank covered with gravel, during the same period, had a surface runoff less than 5 percent and yielded no percolation.

5. Between the end of June and the first of November, however, no percolation was registered from the mulched, tree-covered surfaces, while in the gravel-covered tank percolation amounted to 42.5 percent of the total rainfall.

6. Since the mulched, tree-covered surfaces and the gravel-covered plot received the same amount of precipitation, yet the former did not yield any percolation while the latter allowed a relatively high amount of water to come through, it would indicate that the mulched, tree-covered surfaces lost this amount into the air through transpiration and evaporation.

7. The lysimeter experiments, although of short duration, indicate that in a temperate climate forest vegetation during early summer and late fall traps water on the surface and transmits it to underground reservoirs. During the summer months, however, when the foliage is fully developed, the forest vegetation uses practically all the moisture that falls, and reduces percolation. What effect this forest cover will have when it develops into a dense stand of saplings 5 to 6 inches in diameter, only further observations can tell.

TIMBER CUTTING EXPERIMENTS

Summary of Findings

Jack Pine

1. Ten-year remeasurement of cutting plots in dense 60-year-old jack-pine stands shows that, if jack pine is to be managed for pulpwood production, cutting out of the larger trees yields the greatest growth. In stands in which the small trees were removed and the large trees left, the growth amounted to about 2 cords in 10 years, but in thick stands where most of the merchantable pulpwood was cut the growth in the last 10 years was about 9 cords. At such a rate of growth the stands in which the largest trees were removed will yield a second merchantable cut in another 5 years or so. The small increase in growth of the larger trees, due to thinning from below, makes it doubtful whether holding over the large trees for sawlog production is a desirable practice.

2. The success of securing natural reproduction of jack pine by scarifying the ground and then scattering the slash containing cones, which was demonstrated on the Superior National Forest, has been confirmed on the Huron National Forest in Michigan and on the Chippewa National Forest in Minnesota. As many as 22,000 seedlings per acre were obtained by this method, whereas poor reproduction or none resulted where the soil was not scarified and the slash not scattered.

Selective Logging in Hardwoods

1. The original half-section of old-growth hardwoods has now been practically all cut over under various methods of cutting varying from clear cutting to very light cutting.

2. The cutting experiments, some of which have been in effect over 10 years, now definitely show that selective logging in which about 30 percent of the stand is removed yields silviculturally the best results. The net annual growth under such cutting is about 200 board feet, while the mortality is about 25 to 30 board feet. The silvicultural phase of the study in the pure hardwood type, therefore, may be considered essentially completed. However, much remains to be done in the hardwood type associated with hemlock and other conifers.

3. With the increase of the experimental forest to about 5,000 acres, we can now enter into a new phase of selective logging, viz., sustained yield. This was, of course, impossible heretofore on a small tract of 320 acres.

4. The new tract, by using the best silvicultural experience gained from the previous cutting experiments, will be handled on the basis of continuous production, improvement of the stand, and obtainment of the highest maximum growth within the shortest possible cutting cycle.

Managing Jack Pine for Pulpwood

With the increasing demand for jack-pine pulpwood, operators are turning more and more to young second-growth stands for their supply. Much of this now comes from farm woods. Farmers close to a wood market have depended strongly on their woodlots for a livelihood during the depression years. Besides harvesting ripe timber, they have cut heavily into young stands in order to convert their labor into cash. In their desire to market every stick of pulpwood possible, they have removed not only merchantable trees but also many undersized ones, with the hope that they could "smuggle" them through at the delivery point. The usual outcome has been that sharp-eyed scalers have culled heavily for small sticks. The net result is that the farmer loses the labor spent in cutting small trees, the cost of hauling them to market, and above all he depletes the growing stock of his woodlot, thus destroying prospects of future returns.

How to handle young jack-pine forests is a problem not limited to farm woodlots, but confronts the managers of public forests as well. For example, on the Superior National Forest there is estimated to be 150,000 acres in a single age class (42 years). These "pulpwood" or pole stands of jack pine are generally overstocked, often containing over a thousand trees per acre and various quantities of pulpwood, depending on age, degree of stocking, and quality of soil. Usually there is a preponderance of trees under merchantable size.

In such stands the question is not how to obtain regeneration but how and at what age to thin. Thinning from below, that is, removal of small undersized trees in the hope that this would stimulate the growth of the larger trees, has been carried out on thousands of acres during the past 4 years by the CCC. Even though an acceleration in growth may result, the cost has been so great under the standards set up for the work that

there is practically no chance of recovering the investment through increased growth or stumpage value. The product being of relatively low value and the territory often remote from market, a simple, cheap, practical method of treatment must be devised for handling pole-sized jack pine.

Some form of commercial thinning would seem to be the answer. Experimental cuttings made in a 60-year-old overstocked stand on the Superior National Forest in 1926 offers a clue to the problem.

Three methods of treatment were tried: (1) thinning from below, (2) thinning from above (a 6"-diameter-limit cut), and (3) selection cutting which removed the largest and smallest trees, leaving the intermediates. Although from 13 to 17 cords of pulpwood per acre were taken off each plot, only the thinning from above can be considered a truly commercial cut, since on the other two areas some small unmerchantable material was also removed. After treatment the area thinned from below still supported 16 cords of pulpwood; the selection area, 9 cords. The plot cut to a diameter limit had only 1/2 cord of merchantable wood left, but of course several hundred small trees.

Although the trees on all plots grew at a reasonable rate the first 5 years after cutting, during the last 5-year period all plots except the selection, which made a very slight gain, lost slightly in total cubic volume. Despite this loss in total cubic volume, all plots now have a greater merchantable volume than 5 years ago, because the mortality has been confined chiefly to the smaller suppressed and intermediate trees.

During the 10-year period, the plot thinned from below increased its merchantable volume only 2 cords, the selection area nearly 6 cords, while the check plot now has a little more than 5 cords more than it did 10 years ago. Strangely enough, the commercial cutting or thinning from above has made far the best showing. This now supports a stand of pulpwood of over 9 cords per acre, even though the growing stock had been reduced to 1/2 cord at the beginning of the period. This growth is all occasioned by the growing of unmerchantable 4- and 5-inch trees into 6- and 7-inch classes which are large enough to be merchantable. If the present rate can be continued for another 4 or 5 years, there will be sufficient timber to warrant a second cutting for pulpwood.

The drawing of broad conclusions from a single set of small plots is, of course, not justified. T he trends brought out in this study, however, warrant serious attention. The heavy mortality now going on in the forest points to the maturity of the stand and warns against too optimistic hope for managing 60- to 70-year-old jack pine on a two-cut basis. Incidentally, the mortality was far greater the past 5 years than the first 5 of the study. This may be attributed to greater age, but the more likely reason is that 4 of the past 5 years were abnormally dry. In 1934 there was only 17 inches of precipitation, whereas the normal is 27 inches. The past year (1936) was only slightly more moist.

The most interesting point suggested by the study, however, is this: If a 60-year-old stand of jack pine can be successfully managed on a diameter-limit basis, why is it not entirely feasible to apply such a method to stands 40 or 50 years old? Younger stands should react more quickly and more favorably.

It is planned, therefore, to install a large enough number of thinning plots to determine conclusively the economic and silvicultural feasibility of handling pole stands of jack pine for the production of pulpwood by commercial thinnings from above. The Superior National Forest will supply all the labor and technical help to establish the plots, and the Station will provide the necessary plans and general supervision.

Soil Treatment Stimulates Jack Pine Reproduction

After unsuccessful attempts to obtain jack-pine reproduction on some 12 different sample plots, a method was finally worked out by the Station on the Superior National Forest which points the way.

The procedure followed was (1) to prepare the ground by scarification of the soil, (2) cut and remove the timber, (3) scatter the slash and leave it exposed to the sun until the cones were open and the seed dispersed, (4) dispose of any heavy concentration of slash by piling and burning.

The soundness of these principles has now been demonstrated with equal success and in a more practical way on the Chippewa National Forest in Minnesota and on the Huron National Forest in Michigan. In the case of the Chippewa plots a spring-tooth harrow drawn by a horse was very effective in the soil-preparation work, and on the Huron plots a tractor-drawn disk harrow worked equally well.

An interesting point about these last two trials was the time at which germination took place. During the early summer extreme drought and heat prevailed, a condition entirely unfavorable to the germination of seed but ideal for opening the cones. Rains, however, began late in August and germination promptly occurred. In the case of one plot on the Chippewa, this amounted to some 22,000 seedlings per acre. Late in the fall after fairly severe freezing there were still ample seedlings. Snow now protects them so that a fairly good survival may be expected. On the other hand, an open fall on the Huron Forest, without snow but with low temperatures, may cause heavy losses of seedlings.

Sustained Yield in Northern Hardwoods

Sustained-yield forestry in the Lake States, despite wide publicity of the idea, is still largely a dream. To be sure, some few companies operating in northern hardwoods are practicing selective logging. With the extension of highways and the transition from large railroad operations to small truck-logging jobs, there will undoubtedly be more selective cutting done in the future. But the fact remains that there is no concrete demonstration of sustained-yield management of a specific forest tract. Sustained yield, with all the name implies (annual part-time employment of local settlers, balancing cut against growth, etc.), will therefore be the central motive behind the management of the new 5,000-acre Upper Peninsula Experimental Forest.

Frequent Light Cuts Advocated for Experimental Forest. To apply this form of management to this tract of northern hardwoods, frequent but light cuts, removing from 20 to 30 percent of the volume, are necessary. Five-year measurements of permanent sample plots on four cutting units where light cuttings were applied indicate that an annual growth of about

200 board feet per acre can be expected in the hardwood type on this forest after deducting for mortality.

The 10-year measurement of one of these cuttings (22-inch-diameter limit cutting in which 29 percent of the volume had been removed) shows an annual net growth of 224 board feet. Mortality remained about constant during the 10-year period, 25-30 board feet per acre per year. The applicability of light selection cuttings have thus been amply demonstrated during the 10 years that silvicultural studies have been carried on at the Upper Peninsula Experimental Forest.

To place an area in shape for permanent sustained-yield management and intensive utilization of all products, it is first necessary to install transportation facilities. Nine miles of double truck-trail roads planned for the new Experimental Forest are now 85 percent completed, and 35 miles of forest ways are about one-third done. With a continuance of CCC and ERA, it should be possible to complete the transportation system entirely by the end of the calendar year.

STATISTICAL ANALYSIS OF FOREST MEASUREMENTS

1. The original Forest Mensuration studies confined to forest measurements have now been expanded to include the use of statistical methods in all forest projects, especially Forest Survey, planting, and other sample-plot work. For all practical purposes it has become now an all-Station service in analyzing and interpreting field data.

2. One of the first problems on the Forest Survey was to determine what degree of accuracy could be claimed for line-plot surveys with different spacing of lines, also how large the survey units would have to be to provide reliable figures with wide spacing of lines. Analysis was made of several counties previously surveyed, and the first units completed in Minnesota were subjected to rigorous statistical appraisal. In general it was found that lines 2 miles apart gave good results for counties of 400,000 or 500,000 acres, but that with lines 10 miles apart the survey units would have to be about 4 million acres to give reliable estimates by species. The results of these studies have been written up in detailed memoranda and in one published article in the Journal of the American Statistical Association.

3. A second important Forest Survey problem was preparation of volume tables. For one reason or another most of the earlier volume tables were found inapplicable. A simple method of constructing tables was devised which, with measurements obtained on the Survey, permitted construction of new tables for practically all commercial Lake States species. Tables are also being prepared for the trees of Kansas. A manuscript describing a simple method of constructing board-foot volume tables has been presented for publication. The method utilizes a new conception of merchantability.

4. Another important phase of the Forest Survey project requiring expert statistical work was growth estimating. A general plan of measurement and computation was devised for field crews by which current growth

was estimated for Minnesota, Michigan, and Wisconsin.

A method of predicting growth of uneven-aged northern hardwoods was devised and a yield table prepared for this type. Work was done on mortality in well-stocked and understocked stands. Acceleration of growth due to partial cutting has been reduced to a formula basis by adaptation of an old German procedure. Three manuscripts have been prepared for publication.

Yield tables for other types are being made up from Forest Survey measurements.

5. Methods of sampling the results of forest planting, thinning, and other cultural operations, which have hitherto been on a rather hit-or-miss basis, have been revised upon the basis of approved statistical methods. The field results are now given critical examination to judge their reliability and significance.

6. The Station is cooperating with J. W. Girard of the Washington office in preparation of a "Cruiser's Handbook," which as the name signifies will be a booklet addressed to rangers and practical woodsmen who have the job of estimating timber. In addition to simple description of standard methods, many rules of thumb and practical shortcuts based upon years of Girard's experience and that obtained by the Forest Survey will be incorporated.

7. To meet repeated demands for conversion factors for cordwood of various kinds, all available information on the subject was rounded up and a table prepared showing average volume of solid wood in piled cords of the common kinds of wood.

Field work was completed for a study designed to check the jack-pine cordwood volume table and also for determining volume of the bark, shrinkage and settling in the piles, and the amount of cull.

FOREST ECONOMICS

Summary of Findings

1. Only a very small proportion of the land involved in long-term delinquency in the northern Lake States is bonafide farm land. The problem is mainly a forest problem. This removes a psychological barrier which has been troublesome for a decade.

2. This tax-delinquent forest land, contrary to common belief, is not all devastated and waste land. Fairly large tracts of valuable young timber and even mature timber are involved in some localities--evidence that, in some places at least, we have unwise taxation rather than lack of intrinsic worth of land as a cause of tax delinquency.

3. Under present policies or lack of policies, however, delinquent lands are being progressively despoiled by trespass or by operations approved by county authorities.

4. The tax problem has reached a virtual impasse in certain northern counties. Landowners cannot pay the taxes now exacted. Townships and counties cannot pay their debts and function with present revenues. Unquestionably some outside aid is going to be required. State aid, however, should be directed toward either building up the resources or providing some other means of self-supporting existence. Subsidies that merely perpetuate an abnormal economic situation defeat their own end.

5. The recent lumberjack strike in northern Minnesota calls attention to the stake which labor has in the forest program. Employment in the woods is unstable where industries are unstable and where resources are inadequate to guarantee future permanence. Satisfactory wages and working conditions will be assured only if industries founded on a continuous supply of forest products can be developed.

6. The Forest Survey has shown that a large number of important wood-using industries are doomed if the traditional methods of timber harvesting are followed. Not only sawmills but pulp mills, veneer mills and many secondary industries will be forced to close within the next 20 to 25 years. This will affect not only employment in the mills and camps, but will have wide effect upon farmers, merchants, railroads and, in fact, most phases of community life in the timber districts.

7. On the other hand, the Survey has shown that most districts have sufficient timber left and sufficient advanced second growth to form the basis for sustained operations, possibly on somewhat smaller scale than at present. Changes in operating methods will, of course, be necessary.

8. The acquisition of land for national forests has had a mixed effect upon local problems. In general, not enough land with commercial timber has been acquired to affect adversely the tax base, but in a few localities such as in Forest County, Wisconsin, and Cook County, Minnesota, claim has been made that the public forests have removed so much from the tax rolls that county governmental functions can no longer be carried on. Application for changes in Federal aid have been based on these cases.

9. Too little merchantable timber has so far been acquired by the State and Federal Government to affect profoundly the course of timber liquidation. The Lake States situation clearly calls for a much more ambitious plan of public purchase of merchantable timber or more effective means of guiding the course of private management.

10. Farm woodlands are a potential resource which has been too largely neglected. Economic obstacles, pressure on land for pasturage, lack of suitable markets, and absence of any organizations for marketing forest products have done more than anything else to reduce the condition of the woods and the income from the woods to a deplorably low level.

11. The Forest Survey directly and indirectly has contributed to the technique of sampling, more accurate timber estimating, preparation of board-foot and cubic-foot volume tables, determination of growth in even- and uneven-aged stands, and determination of cull percentages and grades for standing timber.

12. About 80 million acres had been covered by surveys at a cost of about 1/2 cent per acre by the end of 1936. This completed field work in Minnesota, Michigan, and Wisconsin except for 240 miles to be run in the spring of 1937.

13. The final results of the survey are to be included in 13 unit reports and 10 map quadrangles in addition to 3 state reports and a regional report covering the 3 states. To date 4 unit reports and 3 map quadrangles have been issued. Three additional unit reports and the first state report are nearing completion.

14. The only specific appropriations available to the Station for economic studies have been for the Forest Survey and the New Public Domain project. Need has appeared for work along a number of other lines, of which the following are most important.

Forest Labor and Employment Studies Needed

In the past, foresters have commonly thought in restricted terms of increased timber production and improved physical conditions of the forest. Recent years of economic depression have emphasized the importance of interpreting forestry activities in terms of human benefits. Of outstanding importance is the problem of improving and stabilizing employment in the woods and in forest industries. Little is known of the present status of resident labor as to incomes, living and working conditions, its adaptability for woods work, the amount of such labor available, and the form of forest organization which would be best adapted to its needs. The problem is equally important to the workers themselves and to the forest industries. The relationship of forests to labor is clearly a social problem of major importance.

Woodland Study Proposed

The possibility of improving farm conditions and farm income through better management of farm woodlots likewise deserves greater attention. The Station has done some preliminary work in this field in connection with the Forest Survey. It has become apparent that the economic factors in woodlot management are among the most difficult problems. The organization of the woodlot as a productive element in the whole farm economy, and determination of the amount and quality of available resources with the idea of bringing in new industries to provide better markets, are matters which go hand in hand with the more technical phases of woodlot management. It is possible that such studies will lead to the ultimate development of cooperative organizations for marketing forest products or even for forest management. An item is included in the 1938 budget to permit inauguration of these studies. If funds are made available, a cooperative project will be undertaken in central and southwestern Wisconsin involving the Forest Products Laboratory, the University of Wisconsin, the Conservation Commission, and the State.

Cost and Price Studies

In general, the silvicultural phases of forest management are far in advance of economic analysis, and the rank and file of foresters are

only beginning to think in terms of costs and returns. One of the reasons has been the absence of reliable tools to work with and the absence of any agency to collect, disseminate, and analyze economic facts as is done with silvicultural material.

Lack of reliable current statistics on prices of forest products, transportation costs, costs of milling, and costs of logging have been a serious handicap in all types of forest economic studies and particularly in making stumpage appraisals and management plans. Even the costs of protection, maintenance, and management are handled merely as loose approximations. A systematic program is needed to assemble these figures currently or at regular intervals. No large amount of field work would be involved.

Recreation

Recreation, a 90-million-dollar industry in Minnesota and much larger in Wisconsin and Michigan, is primarily a forest industry. This industry (which in Minnesota directly employs 22,000 people) must have exerted a highly important influence on the local tax situation and in the employment of labor, both of which have been aggravated by the closing down of the lumber industry.

In order to make an intelligent analysis of either the tax-delinquency question or a study of labor in the lumber industry we should know the answers to the following questions:

1. To what extent have taxes paid by the recreation industry solved local tax problems caused by denudation of forest land, and what are the future prospects?

2. To what extent has the increase in recreation taken up the slack in unemployment of labor stranded by the decrease in the lumber industry? What may be expected in the future?

Extension of Survey

Besides finishing the field and office work already under way in the Forest Survey, there are several activities which logically should be carried out by the Station organization, among which the most important are:

1. Setting up machinery for keeping statistical data up to date. This will involve:

(a) Cooperation with Census Bureau and some independent work to obtain reliable lumber, pulp, and other wood production figures year by year.

(b) A periodic check-up of farm production, sale, and use of forest products.

(c) Observation of permanent plots or larger tracts well scattered over the region to keep in touch with trends, both physical and economic.

2. Localizing survey data--that is, to translate and refine some of the present data into terms of significance to particular communities, industrial groups, counties, etc. The Station cannot do this alone, but by participating with other agencies it can have a coordinating influence, raise the standards of local work and, by providing a suitable repository for records, assure that the results of scattered and unrelated projects will not be lost.

3. Further studies of wood requirements in the Lake States and adjoining areas. This would be a market study to determine the quantities and kinds of woods used in the nearby Plains and Prairie States; current trends; what factors determine the choice of species and regions of origin. In short, what is the future of Lake States timber from the demand standpoint.

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117 "Winter Injury to Plantations."

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